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THE ROLE OF TREES IN ENHANCING OUTDOOR THERMAL COMFORT DURING WARM SEASON IN A SUB-HUMID CLIMATE. CASE: SOUK AHRAS CITY

Abstract: Enhancing the quality of life for people in urban areas necessitates focusing on outdoor thermal comfort OTC. This study examines the role and impact of urban vegetation, particularly trees, in improving the meteorological conditions that characterize the urban microclimate in order to enhance OTC, focusing on two public spaces in Souk Ahras city, characterised by in situ measurement campaigns and modelling during hot summer day. In situ campaigns were carried out to measure climatic data (air temperature, relative humidity and wind speed), and to collect data on vegetation (trees) and building geometry, which were used in numerical modelling to calculate the various thermal indices: SVF, Tmrt, PET and OUT_SET using the Rayman microclimatic model. The results show that the trees at each intervention site can reduce the average daily air temperature of 0.376◦C to 1.04◦C and an enhancement of thermal comfort in terms of average radiant temperature Tmrt of 2. 08° ◦C to 5.85◦C and equivalent physiological temperature PET of 1.91 ◦C to 3.84◦C and standard equivalent temperature OUT_SET of 1.72◦C to 2.86◦C. in the knowledge that trees also help to reduce the Skye view factor, an essential geometric measure for assessing the thermal environment, which proves that the effect of shading and evapotranspiration provided by trees mainly contribute to enhancing outdoor thermal comfort during the warm season.

Key words: heat stress, trees, outdoor thermal comfort, thermal indices

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Introduction

While climate change continues to worsen, cities are seeing an increasing number of extreme phenomena, such as the intense urban heat island UHI (Gatto et al., 2021). The threat of excessive heat can have a variety of negative effects, such as decreased thermal comfort, an increase in heat-related illnesses and deaths, deterioration of air quality and, increased energy consumption for cooling (Liu et al., 2021). Additionally, this excessive heat also has potential negative effects on citizens' outdoor thermal comfort OTC (Meili, 2021).

Urban outdoor spaces provide a variety of purposes, including social, cultural, hygienic, functional, economic, and ecological ones As a result, they are increasingly recognized as essential elements that contribute to both environmental sustainability and the quality of urban life (Kumar & Sharma, 2020).However, because outside temperatures are far higher than inside temperatures, few people can spend extended periods of time outside, especially during hot days when there aren't any pavilions or cooling centers (Zhang et al., 2022). One of the most effective strategies for improving outdoor thermal comfort through a number of processes is the use of urban vegetation in cities (Clarence & Gamini, 2022). When it comes to regulating the climate and lowering the temperature, trees are more useful than other vegetation components (Heng & Chow, 2019). The ideal number of trees to shade an area can be determined in different ways; calculating the sky visibility factor (SVF) is the basis of one of the most widely used methods (Ahmadi Venhari et al., 2019). It has been widely used in studies of urban climates, including thermal comfort. In order to assess thermal comfort, researchers have employed a number of indices, which are vital biometeorological measurements that characterize the impact of both indoor and outdoor thermal comfort. They mainly relate human thermal perceptions to local microclimatic variables (Xiao & Yuizono, 2022) such as the physiologically equivalent temperature PET, the outdoor standard effective temperature OUT_SET.

The Souk Ahars city, located in the north-eastern part of Algeria, is affected by the urban heat island phenomenon. This study's main goal is to investigate the outdoor thermal comfort in it and the effects trees, on the enhancement of the OTC in a situation of thermal stress. The study's findings will be helpful in improving the city's livability with regard to urban planning and space arrangement. However, during the heat stress period (between July 15 and 18, 2022), in-situ measurements of the three climatic data (Ta, RH, and Va) were conducted to compare them in two distinct public spaces the E-Serdouk square and the Independence square over a total of 6 points. This was followed by numerical modeling using Rayman 1.2 software (Matzarakis et al., 2010) to analyse the outdoor thermal comfort at each point on the basis of the following indices: the SVF, the Tmrt, the PET and OUT_SET*.

Materials and methodology

In order to study the outdoor thermal comfort and the effects of trees on improving it in a heat-stress situation, we used an empirical approach based on two methods: in situ measurements and numerical modelling (see figure 1).

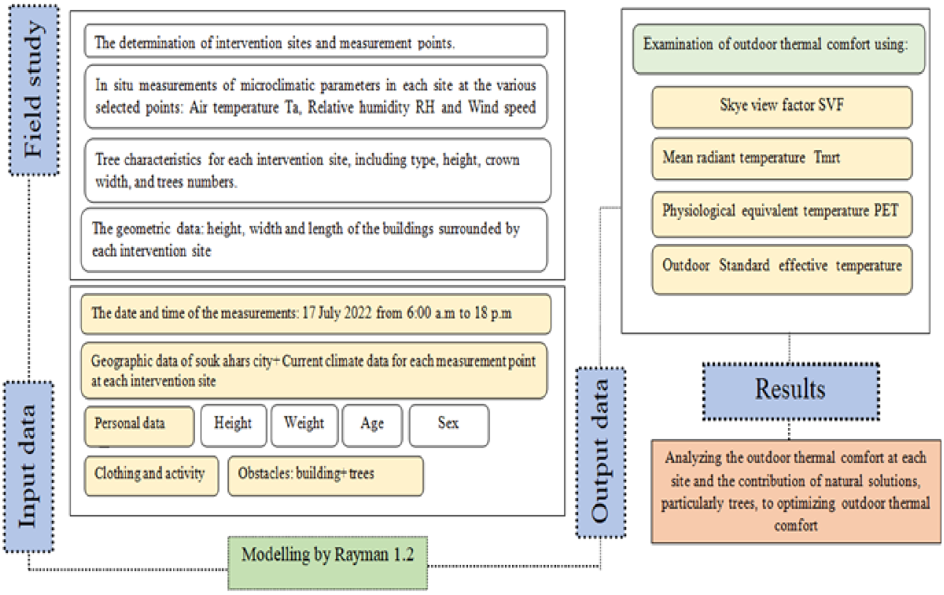

Fig. 1. The research's foundational structure (Source: author, 2023)

Study area

The geographical location of the study area

The region of Souk-Ahras is situated near Algeria's borders in a naturally occurring passage between Tunisia and the rest of the country. It is situated in the northeast of the country (36° 17′ 15 North, 7° 57′ 15 East), at an elevation of 697 feet above sea level. Covering an area of 4,359.65 km², the region of Souk-Ahras accounts for just 0.18% of Algeria's total surface area.

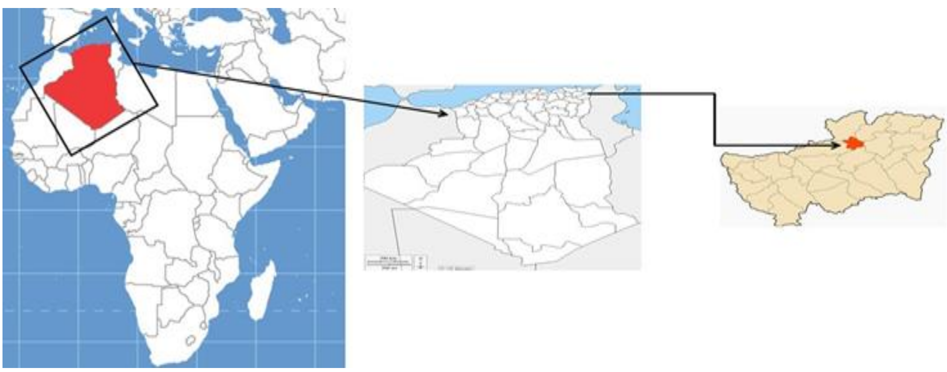

Fig. 2. Geographical location of the study area (Source: author, 2023)

Climate overview of the study area

Located on the heights of the Tellian Atlas, the region of Souk Ahars is exposed to Mediterranean climatic influences in the north and desert influences in the south (see Figure 3), according to the Koppen-Geiger (Csa) classification.

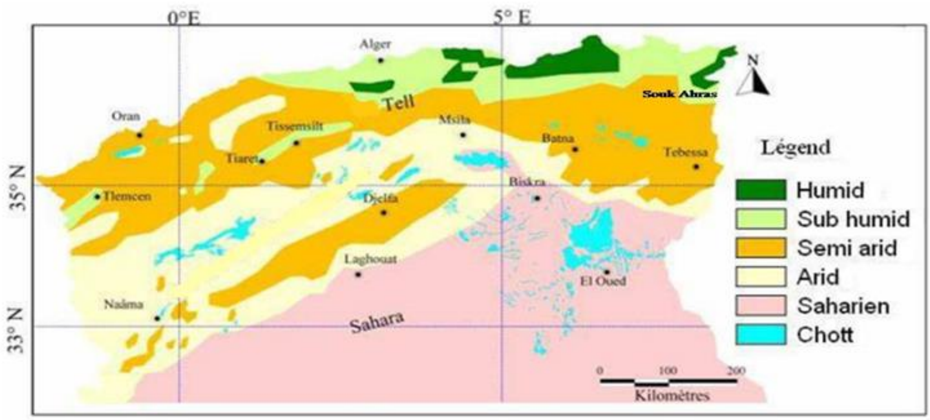

Fig. 3. The bioclimatic map of Algeria (Source: Houamel, 2018)

The climate is characterised by a hot, dry summer of 25 to 35°C in July and August, and a cold, wet winter of 1 to 15°C in January (see Table 1).

Tab. 1. Climatic data for the Souk-Ahras region for the period 1996- 2018

Month	Mean maximum temperatures C°	Mean minimum temperatures C°	Precipitation (mm)	Wind speed (Km/h)	Humidity %
Jan	14,65	5.43	88.09	3.34	73.34
Feb	14.76	5.33	35.80	4.27	71.32
Mar	14.87	5.93	165.78	4.22	74.91
Apr	20.56	9.77	78.67	3.54	69.23
may	23.09	11.21	72.99	3.23	68.21
Jun	29.06	15.87	10.54	3.42	58.34
jul	32.72	17.91	4.55	2.90	57.32
Aug	31.34	17.11	5.43	3.10	51.34
Sep	26.71	15.56	38.87	3.10	70.09
Oct	25.50	14.12	18.50	2.60	67.98
Nov	17.72	08.50	55.43	2.80	73.12
Dec	13.41	6.60	36.32	2.90	84.45
Average	22.03	11.11	661.50	3.28	68.31

Source: Souk-Ahras weather station

Features of the intervention sites

Two public spaces were selected for this study; E-serdouk and Independence (see Figure 4).

Fig. 4. The different intervention sites (Source: author, 2023)

E-serdouk square

With its trapezoidal shape and a total surface area of 735.43 m2, the E-serdouk square is located right in the centre of Souk Ahars city (36°16'59.35 "N 7°57'12.29 "E). The northern part of the square is bordered by a cafeteria, which makes it one of the busiest public spaces in the city. The vegetation consists of deciduous trees: a single tree of Ailanthus altissima and Schinus molle and five ash trees (see figure 5).

Independence Square

The independence square is a landmark and a structuring element of the city centre (36°17'4.74 "N; 7°57'22.47 "E). With its rectangular geometric shape, it has an estimated total surface area of 2572.75 m2, although its four sides are limited by mechanical roads. The vegetation is in the form of deciduous trees: nine plane trees and eleven ash trees (see figure 5).

Fig. 5. (a) the existing trees Serdouk square; (b) the existing trees in independence square (Source: author, 2023)

Data collection Framework

A series of in situ measurements were carried out during the heat stress period (between July 15 and 18, 2022) in two public spaces in the town of Souk Ahars, in order to study outdoor thermal comfort and the influence of trees in improving it, which is the main objective of the study. Consequently, a daily recording consisting of six sessions from 6:00 to 18:00 of the three climatic parameters, Ta °C, RH % and Va m/s, was carried out using two certified measuring instruments.

Thermal Indices

The physical equivalent temperature PET index

PET is defined as the temperature of an indoor or outdoor environment which, in a typical setting, maintains the thermal equilibrium of the body while maintaining core and skin temperatures equal to those of the conditions assessed (Höppe, 1999).

Tab. 2. PET classification based on physiological stress and different heat perception levels

PET (◦C)	**Thermal perception**	**Grade of physical stress**
> 41	Very hot	heat stress
35 -41	Hot	Strong heat stress
29 - 35	Warm	Moderate heat stress
23- 29	Slightly warm	Slight heat stress
18 -23	Comfortable	No thermal stress
13- 18	Slightly cool	Slight cold stress
8 - 13	Cool	Moderate cold stress
4 - 8	Cold	Strong cold stress
≤ 4	Very cold	Extrem cold stress

Source: Fröhlich & Matzarakis, 2020

*Outdoor Standard effective temperature OUT_SET**

The OUT_SET is an equivalent temperature calculated on the basis of skin heat transfer and certain physiological parameters acquired from the two-node model (Ji et al., 2022).

Tab. 3. SET classification based on physiological stress and different heat perception levels*

SET (◦C)	**Thermal perception**	**Grade of physical stress**
>37.5	Very hot	+ disruption of evaporative regulation
34.5–37.5	Hot	Profuse sweating
30.0–34.5	Warm	Sweating
25.6–30.0	Slightly warm	slight sweat
22.2–25.6	Neutral	thermal neutrality
17.5–22.2	Slightly cool	Initial vasoconstriction
14.5–17.5	Cool	slow body cooling
10.0–14.5	Cold	beginning of shivering

Source: Zhimin Zheng et al., 2021

Rayman model

The Rayman 1.2 micro-scale model has been developed for environmental meteorology. The application is used to calculate the various thermal comfort indices in the two intervention sites over a total of 6 measuring points, including the PET, the OUT_SET, as well as the Tmrt and SVF.

Modelling by Rayman 1.2, the geographical data of Souk Aharas city, such as longitude 7° 57′ 15 E, latitude 36° 17′ 15 N, altitude 697m and time zone (UTC + h) 1; as well as the modelling date (July 17, 2022) and the personal and clothing (0.9 clo) and activity (80 w) data are all filled in. In order to calculate the various thermal comfort indices, the data relating to the physical environment (dimensions of the buildings and trees) of each site over a total of 6 points are all filled in (See figure 6).

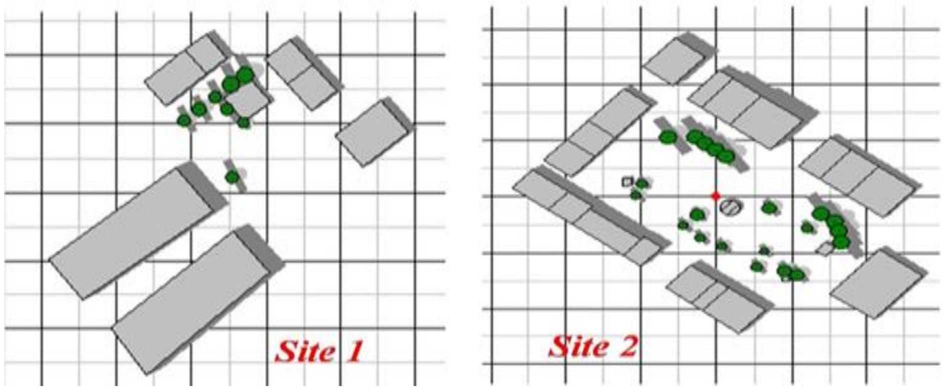

Fig. 6. A representation by Rayman1.2 depicting the physical environment of the intervention sites (Source: author, 2023)

Figure 7 shows Rayman 1.2 modelling of 6 measurement points distributed over the four intervention sites.

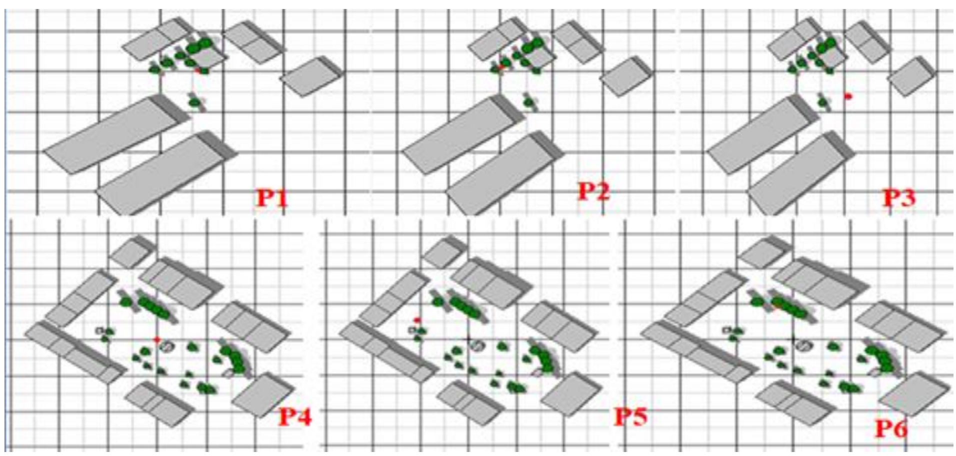

Figure 7: Rayman 1.2 modelling of the 6 measurement points (Source: author, 2023)

The current metrological data: air temperature Ta; relative humidity RH and wind speed Va measured at each point of the 2 intervention sites are presented in table 4.

Tab. 4. Current weather data for the four sites for July 17, 2022

Factor	**Time**	**Site1**			**Site2**		
		P1	**P2**	**P3**	**P4**	**P5**	**P6**
Ta C°	6 a.m	28.7	27.9	28.9	27.1	28.6	26.6
	8 a.m	33.4	33.4	34.1	32.1	32.5	31.4
	10 a.m	34.9	34.1	34.1	38.8	37.8	37.0
	12 a.m	37.2	38.0	39.0	40.5	36.8	36.0
	2 p.m	37.1	37.4	38.8	36.4	35.6	35.8
	4 p.m	33.2	35.8	33.6	32.5	32.8	32.4
	6 p.m	31.2	32.3	31.4	31.2	30.4	30.2
RH%	6 a.m	38.7	34.8	38.6	40.5	36.1	40.9
	8 a.m	30.2	33.8	30.2	31.7	30.7	36.4
	10 a.m	27.8	27.4	29.0	25.0	26	28.0
	12 a.m	24.0	21.1	22.1	22.4	21.4	23.1
	2 p.m	28.5	26.5	28.2	25.2	24.3	25.4
	4 p.m	32.8	28.6	32.4	33.2	33.8	33.2
	6 p.m	34.02	35.8	33.2	34.5	34.2	34.2
V_a m/s	6 a.m	0.65	0.75	0.75	0.55	0.75	0.76
	8 a.m	0.75	1.43	0.60	0.80	0.77	0.80
	10 a.m	0.90	1.90	1.00	0.75	1.60	0.75
	12 a.m	1.10	0.77	0.40	0.75	0.77	1.49
	2 p.m	0.85	1.30	0.85	0.85	0.80	1.02
	4 p.m	0.95	1.20	0.80	0.85	0.95	0.85
	6 p.m	0.90	1.25	0.95	0.95	0.95	0.95

Source: author, 2023

Results

Examination of the various microclimatic measurements made at the intervention sites

Figure 8 shows a parallel comparison of the three climatic parameters measured in Souk Aharas city at the intervention sites, on 17 July 2022, via 6 different points from 6:00 am to 6:00 pm.

The highest Ta value in both sites was recorded at 12:00 a.m. in P4 with 40.5 C°; whereas at 6:00 a.m P6 presents the lowest value 26.6 C°. The point P6 in second site recorded the lowest average air temperature throughout the day, with an average of Ta.average.P6=32.77 C°. At the first site, P1 and P2 had the lowest average air temperatures, with Ta.average.P1= 33.67 C° and Ta.average.P2=34.12 C°. These results are strongly related to the trees near these measurement points. For relative humidity, the highest value was recorded at 6:00 a.m. at P6 in the second site by 40.9%, while P2 in the first site represents the lowest value by 21.1% recorded at 12 a.m. The highest average relative humidity was recorded at P6 in the second site with RH.average.P612 =31.6% while P2 at the first site has the lowest mean relative humidity, with, RH.average.P2 = 29.97%. In addition, at 10:00 a.m. in the first site; P2 was recorded the highest wind speed value 1.9 m/s from where the lowest value is recorded at 12:00 a.m. for P3 with 0.4

m/s. In the first site P2 records the highest means of air speed throughout the day with Va.average.P2=1.22 m/s.

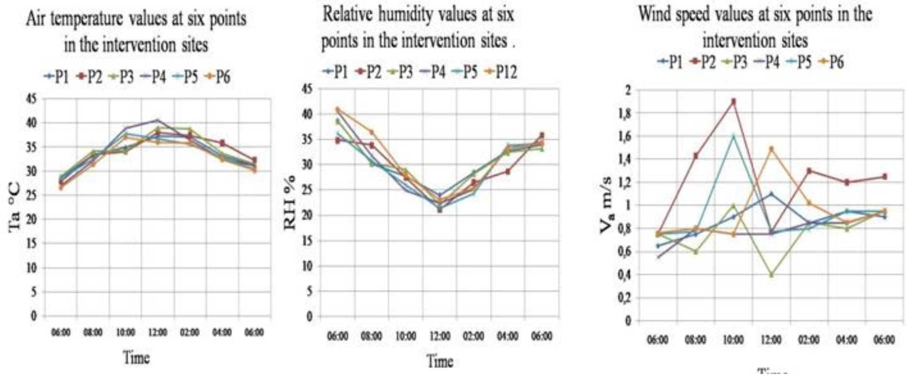

Fig. 8. Current macrological data measured in intervention sites (Source: author, 2023)

Assessment of SVF and heat stress levels

The limits of the horizon for each measurement points are displayed in Figure 9, in the form of a polar coordinate diagram (fish eye view) produced with Rayman 1.2, after the data for the physical environment, whether buildings or trees, has been entered.

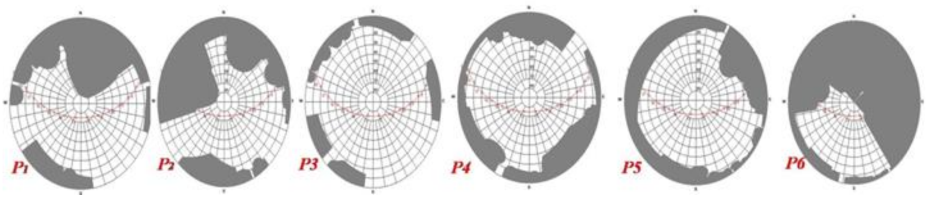

Fig. 9. Polar diagram (fish-eye image) of the measurement points at the intervention sites carried out by Rayman 1.2. (Source: author, 2023)

After analyzing the SVF values obtained from 6 measuring points at the intervention sites (see Table 5), the lowest SVF value is represented by P6 at the second site, with an SVF equal to 0.304, which means a horizon limitation of 69.9%, due to the nature of the measuring point, which is very close to plane trees.

Tab. 5. SVF and horizon limitation values calculated by Rayman 1.2

Point	**P1**	**P2**	**P3**	**P4**	**P5**	**P6**
SVF	0.609	0.530	0.851	0.697	0.676	0.304
H. limitation	39.1%	47.0%	14.9%	30.3 %	32.4%	69.9%

Source: Author, 2023

Tmrt values assessment

According to the analysis of the modelling results, the calculated values of Tmrt in the two sites show that they are very close to the air temperature value at 6:00 a.m and at 6:00 p. m, while the Tmrt values show an increase in the remaining hours of measurement, which means that the Tmrt is very sensitive to solar time (see table 6).

Tab. 6. Tmrt values at the different measurement points calculated by Rayman 1.2

Site	Point	Time						
		6 a.m	8 a.m	10 a.m	12 a.m	2 p.m	4 p.m	6 p.m
1	P1	31.5	56.1	64.6	65.7	66.3	55.9	33.5
	P2	30.4	55.1	61.7	67.1	65.4	49.2	34.6
	P3	31.5	58.0	64.3	*69.8*	68.2	57.4	33.9
2	P4	30.1	55.5	68.0	*69.3*	65.9	55.7	33.8
	P5	31.1	55.7	65.5	66.3	65.4	55.8	32.8
	P6	29.2	44.6	55.2	63.3	64.2	45.4	32.6

Source: Author, 2023

At 12:00 a.m the first site recorded the highest value of Tmrt in P3 with 69.8 C° followed by P4 at the second site with 69.3 C°. On the other hand the lowest value of Tmrt was in the second site at 6:00 a.m for P6 where Tmrt P6=29.2 C°. In the first site P2 had the lowest average Tmrt compared to all the rest of the points with Tmrt .average.P2=51.92 C°. While in the second site the lowest value of average Tmrt was for P6 with Tmrt.average.P6=47.78 C° (see figure 10). It should be noted that points P2 and P6, are measurement points very close to the trees, which means that the trees have an effect on lowering Tmrt values.

PET values assessment

Evaluation of the PET values obtained during the study period at the intervention sites via 6 measurement points showed that there are four different thermal comfort zones: Slightly warm, Warm, Hot and Very hot. From 6:00 a.m. to 4 p.m, PET values increased at all measurement points (see tables 7). At P3 of the first site, a maximum temperature of 56.2 C° was recorded at 12:00 a.m.; this is the highest PET value for the course of the study, causing thermal stress to users who frequent this public area. On the other hand, the lowest PET value was recorded at P6 on the second site at 6:00 a.m. with 26.1 C°, resulting in a slight thermal stress.

Tab. 7. PET values at the different measurement points calculated by Rayman 1.2

Site	Points	6 a.m	8 a.m	10 a.m	12 a.m	2 p.m	4 p.m	6 p.m
3	**P1**	29.1	43.7	48.8	50.6	51.4	43.2	31.4
	P2	27.6	42.2	44.8	52.7	50.4	41.7	32.7
	P3	28.9	45.8	47.8	56.2	53.6	44.5	31.7
4	**P4**	27.3	42.4	53.8	55.6	50.6	42.5	31.5
	P5	28.4	42.8	50.2	51.3	50.0	42.9	30.5
	P6	26.1	36.6	45.9	47.6	49.0	37.6	30.2
Thermal comfort stress level	**23 to 29**		**29 to 35**		**35 to 41**		**> 41**	
	Slightly warm		**Warm**		**Hot**		**Very hot**	

Source: Author, 2023

The results of the PET values obtained in the intervention sites indicate that the lowest average PET values are: at P6 in the second site with PET.average.P6=39 C° and P2 in the first site with PET.average.P2=41.72 C° (see figure10). This lowering is strongly due to the shade cast by the plane and ash trees which are very close to these measurement points. Comparing the second site with the first, PET values are lower, hence PET Average .site 2=41.56°C and PET Average .site 1=42.97°C.

OUT_SET values assessment

According to the analysis of OUT_SET values obtained in the intervention sites via measurement points, five thermal comfort zones are detected throughout the day: Neutral, Slightly warm, Warm, Hot and very hot. The OUT_SET values show an increase from 6:00 a.m. to 4:00 p.m. at all the measurement points, before falling again at 6:00 p.m (see tables 8). The highest value of OUT_SET was 44.3 C° at P3 of the first site, followed by 43.1 C° at P4 of the second site during 12:00 a.m, these two points represent the highest values of Ta and Tmrt throughout the study period where Ta P3=39.0 C°, Tmrt P3 =69.8 C° and Ta P4=40.5 C°, Tmrt P4 =69.3 C°, this result causes increased disruption to the regulation of evaporation for users of this public space. Where P6 of the second site recorded at 6:00 a. m the lowest value of OUT_SET with 28.5 C° which causes a slight perspiration to the users of this public space, followed by P2 at the first site with 23.1 C°, a value recorded to demonstrate the physiological thermal neutrality of the users; bearing in mind that the values for Ta and Tmrt at these two points are the lowest throughout the day, hence Ta P2=27.9 C°, Tmrt P2 =30.4 C° and Ta P6=26.6 C, Tmrt P6 =29.2 C° (see table 9).

Tab. 8. OUT_SET values at the different measurement points calculated by Rayman 1.2

Site	Points	6 a.m	8 a.m	10 a.m	12 a.m	2 p.m	4 p.m	6 p.m
3	**P1**	24.5	35.1	38.6	39.5	40.4	34.7	25.9
	P2	23.1	33.6	35.0	40.9	39.0	33.0	26.6
	P3	24.2	36.9	37.9	44.3	41.9	35.7	26.1
4	**P4**	23.2	34.3	42.0	43.1	39.8	34.3	26.0
	P5	23.8	34.5	38.9	40.3	39.5	34.5	25.2
	P6	22.2	30.1	36.5	37.2	38.6	30.6	25.0
Thermal comfort stress	**22.2–25.6**	**25.6–30.0**	**30.0–34.5**		**34.5–37.5**		**>37.5**	
	Neutral	**Slightly warm**	**Warm**		**Hot**		**Very hot**	

Source: Author, 2023

The results of the OUT_SET values obtained at the intervention sites indicate that the lowest average OUT_SET values are at P6 at the second site, where OUT_SET average.P6=31.45 C° and P2 the first site, where OUT_SET average.P2=33.02 C° (see figure 10). This lower value is largely due to the shade cast by the plane and ash trees that are very close to these measurement points. The second site recorded lower OUT_SET values than the first site, hence OUT_SET Average .site 2=32.99 °C and OUT_SET Average .site 1=34.13 °C, which shows that the second site is more comfortable for users than the first site.

From the results obtained above, we can distinguish two different thermal periods that are related to the evolution of the values of the various thermal indices over the selected day. The first period included the first and last hours of measurement (6:00 a.m and 6:00 p.m) and the second period during daylight hours (from 8:00 a.m to 4:00 p.m).

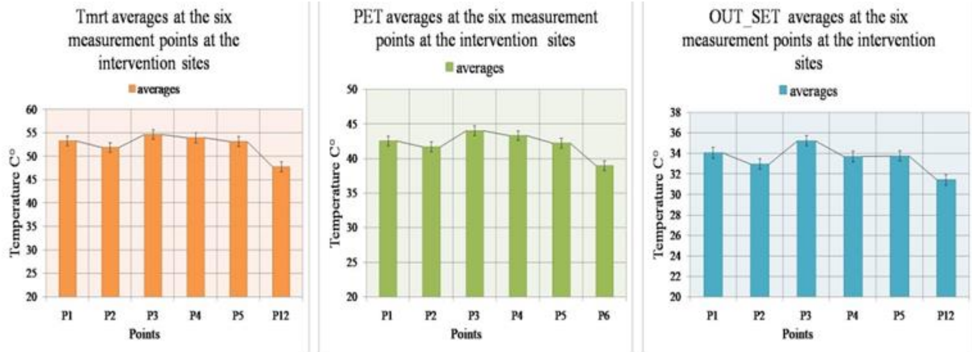

Fig. 10. Tmrt; PET and OUT_SET averages at the six measurement point at the intervention sites (Source: author, 2023)

The vegetation points recorded the best climatic and thermal conditions in the second sites during the selected day of the study, which shows the effect of the trees in these public spaces in enhancing the outdoor thermal comfort of the users who frequent these public spaces (see table 9).

Tab. 9. The climatic and thermal conditions of vegetal points in different sites

P1		P2		P6	
Ta_1	**Va_1**	**Ta_2**	**Va_2**	**Ta_6**	**Va_6**
33.67C°	0.87m/s	34.12C°	1.22m/s	32.77C°	0.94m/s
RH_1	**$Tmrt_1$**	**RH_2**	**$Tmrt_2$**	**RH_6**	**$Tmrt_6$**
30.86%	53.37C°	29.71%	51.92C°	31.6%	47.78C°
PET_1	**SET^*_1**	**PET_2**	**SET^*_2**	**PET_6**	**SET^*_6**
42.6C°	34.1 C°	41.72C°	33.02C°	39 C°	31.45C°

Source: Author, 2023

Assessment of PET, Tmrt, OUT_SET Depending on the SVF values

The minimum values of the thermal indices (Tmrt, PET and OUT_SET) are recorded at the points near the trees P2 at the first site and P6 at the second site. These points have the lowest SVF values, hence SVFP2= 0.530 and SVFP6= 0.304 (see table 10). his shows that the tree canopy increases the percentage of horizon limitation by decreasing the SVF values and in turn the SVF participates in lowering the values of these thermal indices which detect the outdoor thermal comfort of users frequenting these public spaces.

Tab. 10. PET, Tmrt and SET Depending on the SVF values

Point	Horizon limitation	SVF	Tmrt	PET	OUT_SET
P8	47.0%	0.530	51.92 C°	41.72 C°	33.02 C°
P12	69.9%	0.304	47.78 C°	39.0 C°	31.45 C°

Source: Author, 2023

Discussion

Trees' assistance in improving the environmental conditions and outdoor thermal comfort

According to the results obtained from the analysis of the metrological parameters measured in the intervention sites during the study period; the best climatic conditions were represented in the points very close to the schinus molle and ash trees in the first site (P1, P2) and the plane trees in the second site (P6), from where these points marked lower Ta, higher RH and moderate Va compared by the rest of the free points (P3, P4 and P5). The difference in air temperature between the vegetation points and the free points in the intervention sites is estimated respectively at 0.376 °C and 1.02 °C. While the difference in relative humidity values is 0.03% and 1.67 respectively. These recorded differences are due to the particular structure and function of the trees existing in the intervention sites, which enable them to absorb huge quantities of short-wave radiation by reflection and transmission through their leaves, thereby lowering the ambient air temperature in the surrounding area and providing shade and cooling effects through evaporation. Trees transpire, releasing water through their leaves to increase the surrounding humidity and lower the air temperature. These results are consistent with those of (Morakinyo et al., 2016) and (Zheng et al., 2018). Analysis of the SVF values at the 6 points shows that the vegetation points at the interventions sites (P1, P2 and P6) had the lowest SVF values and a high percentage of horizon limitation, which means that the shade provided by the trees had an effect on reducing SVF values and improving the thermal environment, whereas the open areas with barely any shade experienced poor climatic conditions with very high temperatures, causing discomfort for users of these public spaces. These results are in agreement with those of (Lin et al., 2010) and (Zhang, 2019).

Concerning Tmrt, the results obtained from the 6 measurement points in the interventions sites show that the free points are the most exposed to direct solar radiation during the study period compared with the points near the trees, hence the difference in Tmrt is estimated 2.07°C at the first site and 5.58°C at the second site. This difference is due to the shade created by the trees which attenuates the solar radiation, and is consistent with the research carried out by (de Abreu-Harbich et al., 2015). The PET values obtained are influenced by the Tmrt values recorded in all the measurement points at the interventions sites, as well as other climatic factors such Ta, Va and RH (Teshnehdel et al., 2020), the difference in PET obtained between the vegetation points and the free points in the intervention sites is estimated 1.91°C and 3.84°C respectively. This is due to the cooling effect of the trees in blocking direct sunlight, lowering air temperatures and increasing relative humidity, improving the outdoor thermal comfort of the users of these spaces; these results are compatible with those of (Cheung, 2018). The OUT_SET values were clearly influenced by climatic factors such as Ta, RH, Va and Tmrt at the 6 measurement points in the intervention sites throughout the study period (Nazarian et al., 2017), hence the lowest OUT_SET values were recorded in the vegetation points which marked the best climatic conditions due to the existence of trees near these points. While the difference between these points and the free points is estimated 1.72°C at the first site and 2.31°C at the second site, which shows the positive effect of trees on lowering standard effective temperature values and improving the thermal sensation of users of these public spaces.

Conclusion

During the hottest month of the year, July 2022, in Souk Ahras, 2 public places with 6 distinct points were the focus of an empirical study conducted in the city. In order to assess the outdoor thermal comfort in these public spaces and demonstrate the role of trees in enhancing OTC, a series of measurements in relation to the three climate factors were made: air temperature Ta, relative humidity RH and wind speed Va were measured on July 17, 2022. This was followed by numerical modelling using Rayman 1.2 where the calculation is based on 4 parameters: SVF, Tmrt, PET and OUT_SET. The results of this study can be summarised as follows.

First, air temperature and relative humidity are determining factors in outdoor thermal comfort during the warmer seasons. Where a high temperature value causes discomfort to users of public spaces. Second, the phenomenon of evapotranspiration and the shading provided by trees reduces air temperature and increases relative humidity in public spaces. The shadow cast by trees reduces the SVF which means that spaces are less exposed to direct sunlight. Third, the shade created by trees reduces Tmrt and PET values by absorbing huge quantities of short-wave radiation by reflection and transmission through their leaves. Fourth, in addition to air temperature, relative humidity and wind speed; the Tmrt influences the PET and OUT_SET.

Conflicts of Interest: The authors declare no conflict of interest.

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